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AN EXPLORATORY INVESTIGATION OF A WAKE DISRUPTION TECHNIQUE FOR STUDYING WAKE REESTABLISHMENT TIME

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16. Abstract

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High-speed schlieren motion pictures indicated that disappearance of the disrupting jet and reestablishment of the wake-recompression shock were probably occurring simultaneously and that the time from disruptive-jet-air shutoff to wake recompression shock reestablishment was probably between 200 and 450 μsec (flow lengths from 1.8 to 4.2). The values of flow lengths are about one-third to one-half the values measured in impulse facilities in a previous study. This shorter time is believed to be largely due to the difference in flow conditions between the jet disruption technique and impulse facilities.

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AN EXPLORATORY INVESTIGATION OF A WAKE DISRUPTION TECHNIQUE FOR STUDYING WAKE REESTABLISHMENT TIME

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SUMMARY

An exploratory investigation was made of a wake disruption technique for studying the hypersonic-wake reestablishment time in a blowdown wind tunnel. In this technique, a highly underexpanded jet issuing from the base of a 10° half-angle cone totally disrupts and displaces the conventional wake. The jet was rapidly shut off by an explosively actuated valve and the time for wake reestablishment was measured. The tests were conducted in the Mach 6 high Reynolds number tunnel at the Langley Research Center at a stagnation temperature of 506 K and stagnation pressure of 2.86 MPa. The model base jet stagnation pressure was 3.55 MPa at room temperature.

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INTRODUCTION

The time for the establishment of a hypersonic wake is important in reentry vehicle discrimination as well as in the operation of short-run-time impulse facilities to insure that the flow field is fully developed within the test time. Usually the wake formation time is measured in impulse facilities by rapidly initiating the flow over the model. Some recent measurements of this type made in a shock tunnel are discussed in reference 1.

This paper discusses results obtained in exploratory tests using a wake disruption technique to study wake reestablishment times in a blowdown wind tunnel. In this technique, a jet expanding from the base of the model totally displaces the conventional wake. The jet is rapidly shut off using an explosively actuated valve and the time for the conventional wake to reestablish is determined from high-speed schlieren motion pictures.

Attempts were also made to determine the time required for the wake recirculation zone temperature, model base pressure, and model base heat transfer to recover to the undisturbed values.

SYMBOLS

A	area of model base
D	diameter of model base
g	gravitational constant ($1g = 9.8\ \mathrm{m/sec^2}$)
l	length of model
p_b	model base pressure
p_t	stagnation pressure
$R_{e,D}$	Reynolds number at boundary-layer edge based on diameter, $\frac{\rho_e U_e D}{\mu_\infty}$
$R_{\infty,D}$	free-stream Reynolds number based on diameter, $\frac{\rho_\infty U_\infty D}{\mu_\infty}$
T_t	stagnation temperature
t	time
U	velocity
μ	viscosity
ρ	density

Subscripts:

e	value at outer edge of boundary layer
∞	free stream

APPARATUS AND TESTS

Wind Tunnel

The tests were conducted in the Mach 6 high Reynolds number tunnel at the Langley Research Center. This facility is a blowdown wind tunnel with a contoured axisymmetric nozzle and a test section 30.48 cm in diameter (ref. 2).

Model and Instrumentation

Photographs of the model are shown in figure 1. The model, a 10° half-angle cone, was mounted on an insertion mechanism and injected into the airstream after hypersonic flow was established. Contour blocks and an O-ring seal on the mounting plate provided a contoured, sealed test chamber when the model was inserted.

Figure 2 shows a drawing of the model. The model was constructed of stainless steel and machined internally to provide a plenum chamber for a small nozzle located in the base of the model. The nozzle had a 30° diverging section. Small replaceable aluminum inserts with a conical converging section were fitted into the base plate and formed the upstream portion of the nozzle. The aluminum inserts were also the seat for the explosively actuated valve. The throat length and diverging portion of the inserts were constructed in accordance with reference 3, so that the base nozzle also acted as a critical flowmeter for measuring the mass injected into the model wake. An explosively actuated valve was mounted on the model base plate upstream of the nozzle. The valve was fired electrically and was used to rapidly shut off the flow of air through the nozzle. The model base also has provisions for mounting rapid-response pressure gages and thin-film heat-transfer gages flush with the base. A conventional pressure orifice was located on the model base for recording the steady-state model base pressure. Instrumentation leads were brought out through passages in the strut; passages were also used to pressurize the model. Figure 3 is a schematic diagram of the model air-supply system and figure 4 is a schematic diagram of a typical instrumentation hookup.

The pressure transducer was the most sensitive piezotronic gage commercially available with adequate response time. The gage had a sensitivity of 7.25 μV/Pa, which was required to measure the base pressure change, and a rise time of 2 μsec. A thin-film heat sensor with a μsec response time was used to measure the heat transfer. A fine-wire resistance thermometer with a sensor diameter of 0.000508 cm and l/D of about 100 was used to measure the change in wake temperature with time. The response time of the resistance thermometer was about 1 msec. Data were recorded by photographing the screens of the dual-beam oscilloscopes. Schlieren photographs were taken with a high-speed motion-picture camera at frame rates of approximately 4500 per second.

TEST CONDITIONS AND METHODS

Tests were conducted at a wind-tunnel stagnation pressure of 2.86 MPa and stagnation temperature of 506 K, which gave a free-stream Reynolds number per meter of 2.74×10^6. At these conditions, a fully turbulent boundary layer was established about 20.32 cm from the model nose. The model plenum conditions were a stagnation pressure of 3.55 MPa at room temperature.

After hypersonic flow had been established in the wind tunnel, the model was injected into the airstream and the model plenum pressure adjusted to 3.55 MPa. The high-speed schlieren cameras were then started and, after the cameras reached operating speed, the explosively actuated valve was detonated thus stopping the flow of air to the model base jet, and also triggering the oscilloscope sweep circuits. Typical photographs of the model wake for the jet on-and-off conditions are shown in figure 5. The base of the cone just protrudes into the picture on the right side.

RESULTS AND DISCUSSION

Initial tests had indicated that a measurable base-pressure change between jet on and off existed at a model plenum pressure of 3.55 MPa. At this model pressure, the jet from the model base is highly expanded and the conventional wake has been totally disrupted (fig. 5(b)). The mass flow of the jet is about twice the model boundary-layer mass flow at the cone base and about 7.5 percent of ρUA. This mass injection rate is much larger than the rates used in the typical cone base injection studies of references 4 and 5. At a jet-stagnation pressure of 3.55 MPa, the cone base pressure has increased to about 400 Pa with the jet on from 200 Pa with the jet off. This is a ratio of jet total pressure to base pressure of about 8875. Measurements of wake formation time were obtained with the high-speed schlieren photographs and the fine-wire resistance thermometers. However, base pressure and heat transfer measurements were unsuccessful due to the high shock loading of the pressure gage, which occurred when the explosively actuated valve impacted on the valve seat, and to the very low level and small change of base heat transfer.

High-Speed Motion-Picture Schlieren Photographs

The quality of the schlieren photographs was only moderate, due to optical imperfections in the tunnel windows and the low pressure of the undisturbed wake (about 200 Pa absolute). The schlieren knife edge was mounted vertically to minimize the window distortions. The main features of the base jet were apparent, but the recirculation zone was not distinct although the formation of the wake recompression shock could be detected. The wake structure in the schlieren photographs of figure 6 is not as distinct as in the

original 16-mm negatives even though the photographs have been enhanced by a special unsharp dodging technique developed by Leonard Weinstein of Langley Research Center.

A sequence of schlieren photographs of the wake taken at approximately 4500 frames per second is shown in figure 6. At this frame rate, each frame is exposed about 75 μsec and a 150-μsec interval occurs between frames. Consequently, an uncertainty in time exists for events which occur between frames and toward the end of the exposure time.

As can be seen in figure 6, a slight change in the jet structure near the model base has occurred at $t \approx 225$ μsec; air shutoff was probably nearing completion at this time. At $t \approx 450$ μsec, the jet structure forward of the Mach disk has disappeared and at $t \approx 675$ μsec, the wake recompression shock is apparent. Little change occurred after $t \approx 675$ μsec. Jet disappearance and wake reestablishment probably are occurring simultaneously between $t \approx 450$ and 675 μsec and the total time for jet disappearance and wake recompression shock reestablishment is about 450 μsec.

Additional schlieren photographs (not shown) were taken at 4000 frames per second with probes in the wake and with a larger jet-throat diameter. At these conditions, jet disappearance and wake reestablishment required about 500 μsec. This time is nearly the same as the time without wake blockage.

The wake recompression shock always appeared within one motion-picture frame and consequently the time for jet disappearance and wake reestablishment is not known within 225 μsec. In addition, static bench tests indicated that the finite time required for disruptive jet air shutoff might introduce an additional uncertainty of about 150 μsec. However, in the sequence shown in figure 6, air shutoff appears to occur very near $t = 225$ μsec and is rapid compared to the jet disappearance time as indicated by the initial change in jet structure near the model base. A more gradual air shutoff would be indicated by the movement of the Mach disk toward the base of the model as the jet pressure ratio decreased. Both the relatively slow camera framing rate and the air shutoff time tend to make the indicated time for wake reestablishment longer than the true value. Considering these uncertainties, it is estimated that the wake reestablishment time is between 200 and 450 μsec.

Wake Recirculation Zone Temperature

Several tests were made with a 0.0002-in-diameter resistance thermometer and pressure gage in the model wake. The thermometer was mounted 1.59 cm from the model base at the midpoint of the base radius. The installation of both probes increased the base pressure and caused a more complicated shock structure in the wake. An oscilloscope record of this probe is shown in figure 7. The upper trace is the thermometer and the lower trace is the make-wire circuit located on the valve seat. Valve seating is indicated by the sharp rise in the lower trace. The change in probe temperature is nearly complete

about 1200 μsec after valve seating. Since this time is very close to the wire response time, it only sets an upper limit on the temperature reestablishment time which may be much smaller. During tests with only the resistance thermometers mounted in the wake, the change in wake temperature was so small that a time measurement was impossible.

Model Base Pressure and Heat Transfer

Determination of the wake formation time from the change in base pressure was unsuccessful due to the very high shock loading of the gage (about 2000g) caused by the impact of the explosively actuated valve on the aluminum valve seat. A number of techniques including shock mounting, electronic filtering, and probe mounting of the gage were tried in an effort to eliminate the shock loading, but were unsuccessful.

The measurement of a base heat-transfer stabilization time with the thin-film gage was also unsuccessful. This was due to the very low level of base heat transfer and the small change in heat transfer between the jet on-and-off condition, which was obscured by noise at the high amplification settings required to obtain a measurable signal. A number of unsuccessful filtering techniques were also tried with this circuit.

Comparison With Impulse Facility Data

The table below shows wake formation times measured in several impulse facilities and the wake reestablishment times of the present tests.

Reference	tU/D for –		Type measurement	Type facility	Type model	$R_{e,D}$ for –	
	Turbulent boundary layer	Laminar boundary layer				Turbulent boundary layer	Laminar boundary layer
1		30	Pressure	Shock tunnel	Sphere		$(R_{\infty,D})$ 0.16 to 9×10^6
6	10	15 to 20	Schlieren	Shock tube	Hemisphere cylinder	1.11×10^6	1.85×10^6
7	7.6		Schlieren	Shock tube	Hemisphere cylinder	9.85×10^5	
Present	1.8 to 4.2		Schlieren	Jet disruption in blowdown tunnel	Sharp cone	4.4×10^6	

The values of tU/D for wake reestablishment after jet disruption are about one-third to one-half the values for wake formation in impulse facilities. The shorter time for wake reestablishment is believed largely due to the difference in flow conditions. In impulse facilities, the wake is established from a quiescent condition and the entire flow field must be established; whereas in the jet disruption technique, the external flow field is near its established condition and only the disrupted flow must be reestablished. The effect of the difference in model geometry (i.e., a cone in the present tests as compared to a hemisphere cylinder in refs. 6 and 7) may also account for a part of the difference.

CONCLUDING REMARKS

An exploratory investigation was made of a wake disruption technique for studying the hypersonic-wake formation time in a blowdown wind tunnel. In this technique a highly underexpanded jet issuing from the base of a 10° half-angle cone totally disrupts and displaces the conventional wake. The jet was rapidly shut off by an explosively actuated valve and the time for wake reestablishment was measured. The tests were conducted in the Mach 6 high Reynolds number tunnel at the Langley Research Center at a stagnation temperature of 506 K and stagnation pressure of 2.86 MPa. The model base jet-stagnation pressure was 3.55 MPa at room stagnation temperature. The following initial results based on a small number of data points were obtained.

High-speed schlieren motion pictures indicated that disappearance of the disrupting jet and reestablishment of the wake-recompression shock were probably occurring simultaneously and that the time from disruptive-jet-air shutoff to wake recompression shock reestablishment was between 200 and 450 μsec (flow lengths from 1.8 to 4.2). These values of flow lengths are about one-third to one-half the values measured in impulse facilities in a previous study. This shorter time is believed to be largely due to the difference in flow conditions between the jet disruption technique and impulse facilities.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., February 19, 1974.

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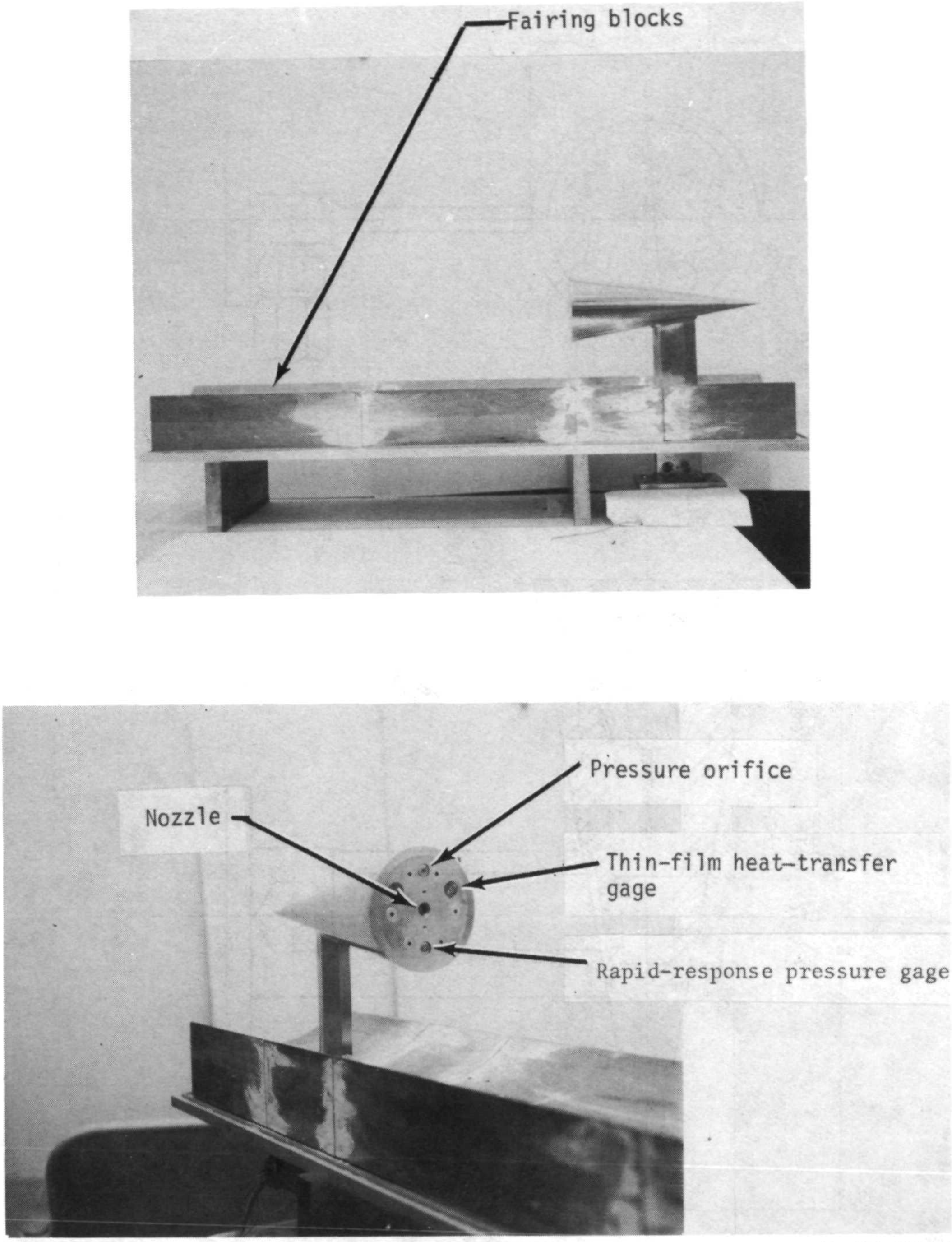

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Figure 1.- Photographs of model.

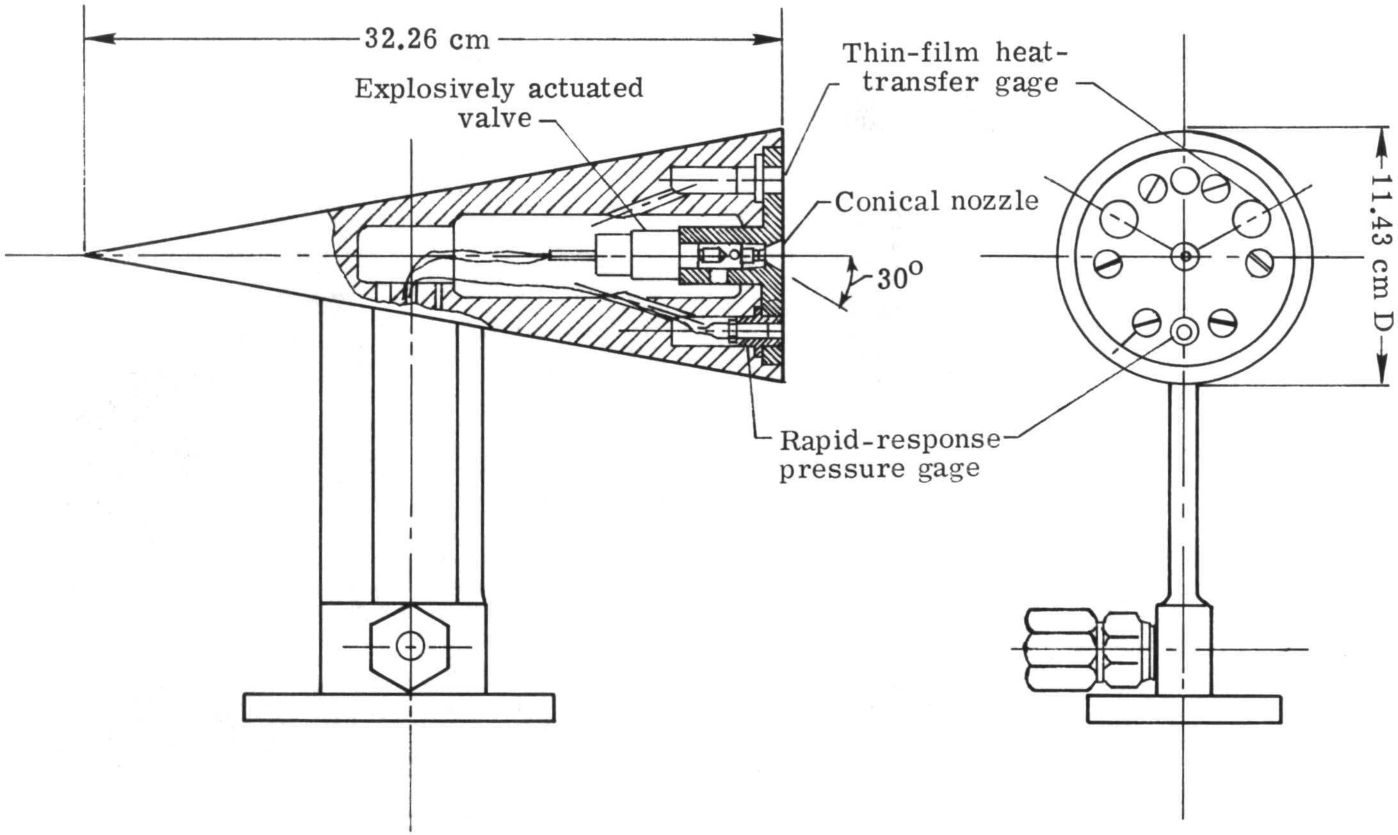


Figure 2.- Drawing of model.

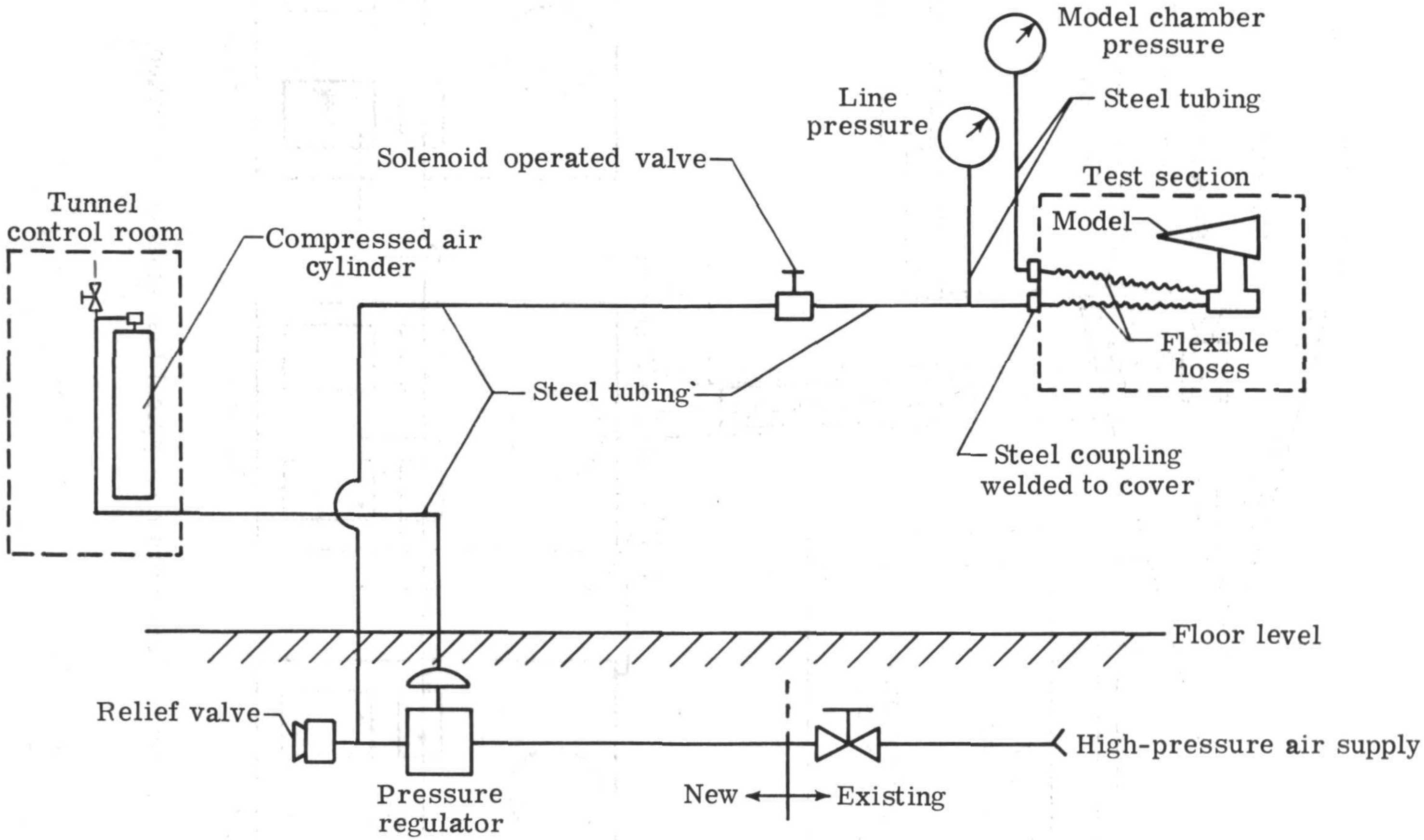


Figure 3.- Model air-supply system.

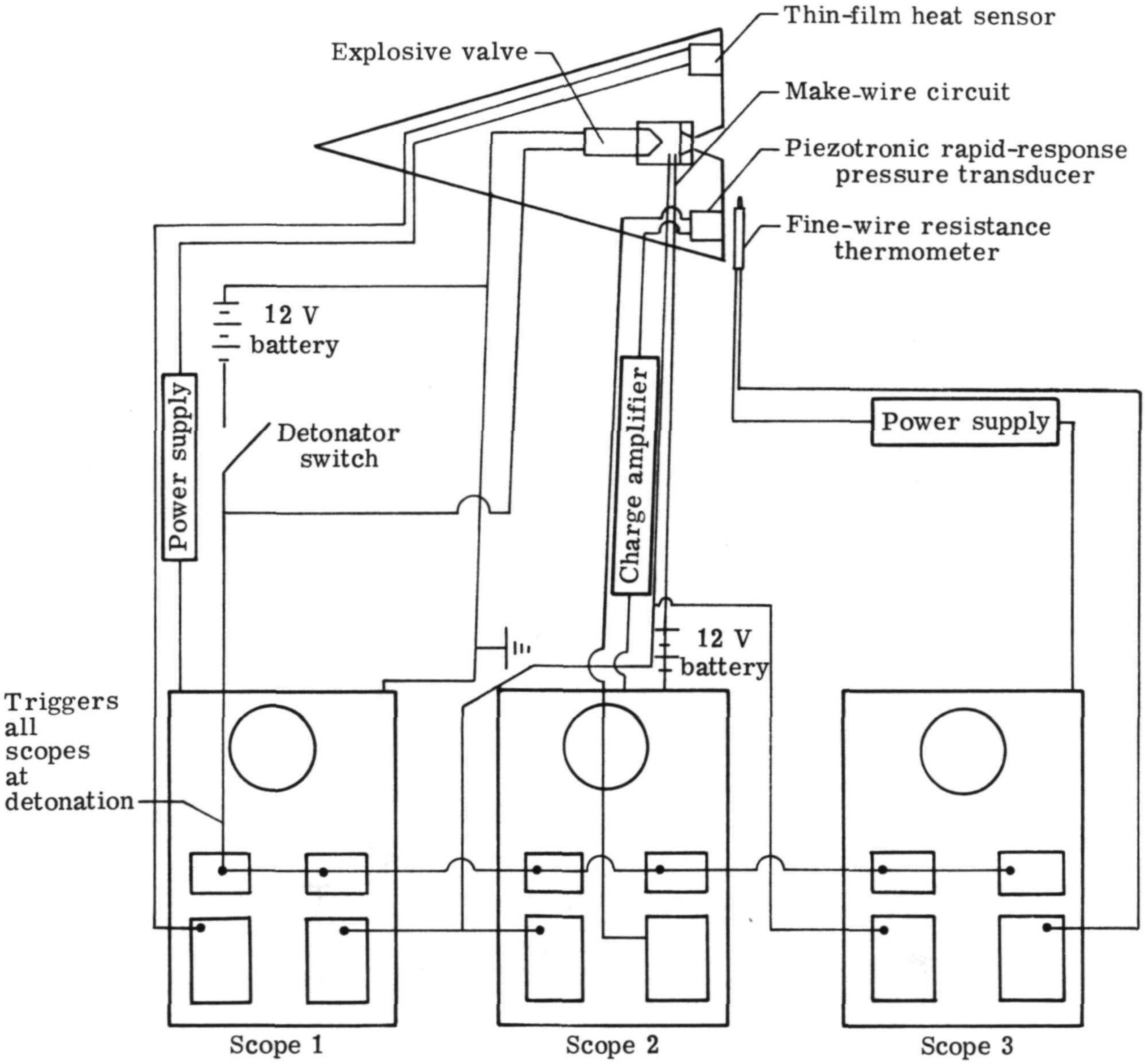
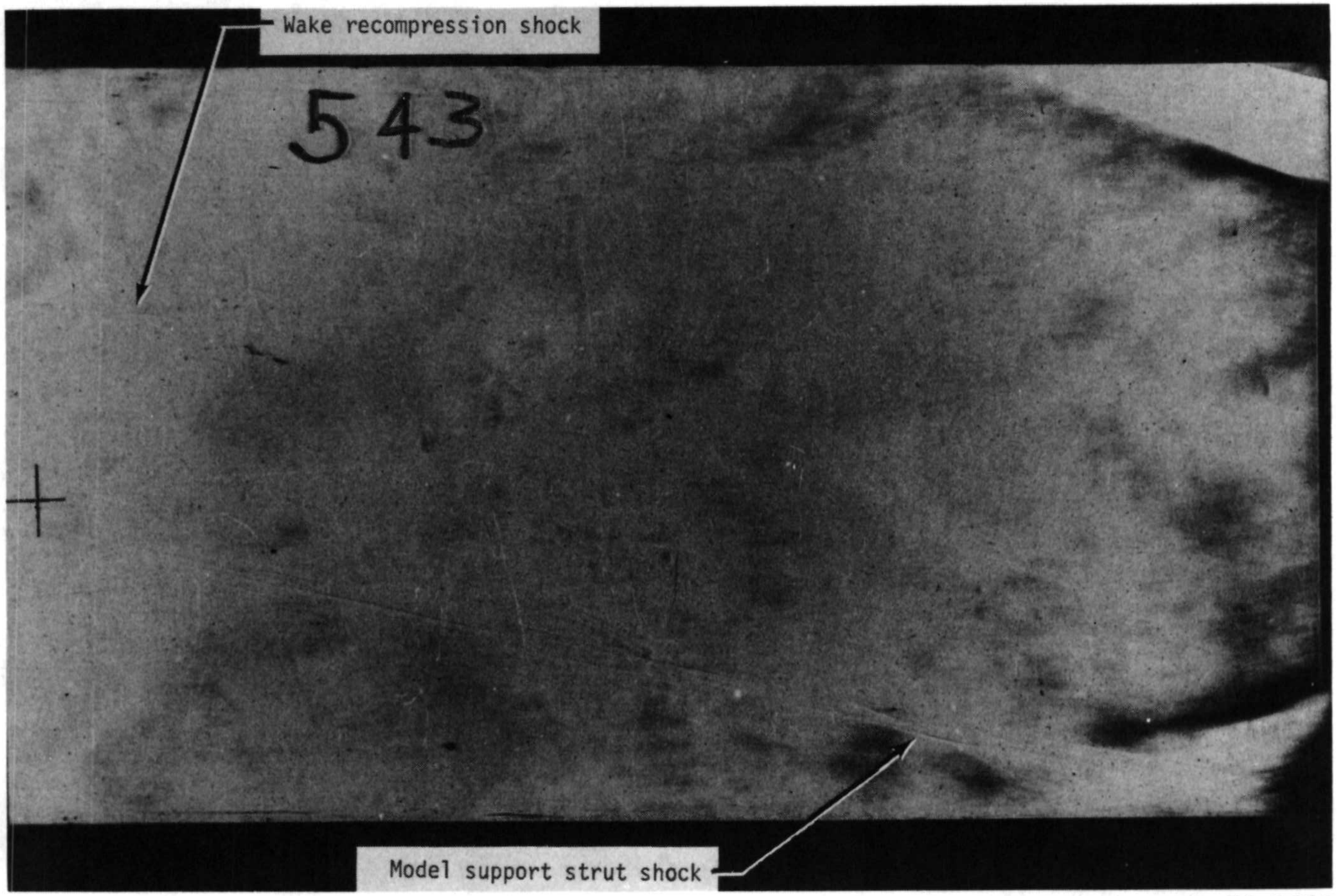


Figure 4.- Schematic diagram of typical instrumentation hookup.



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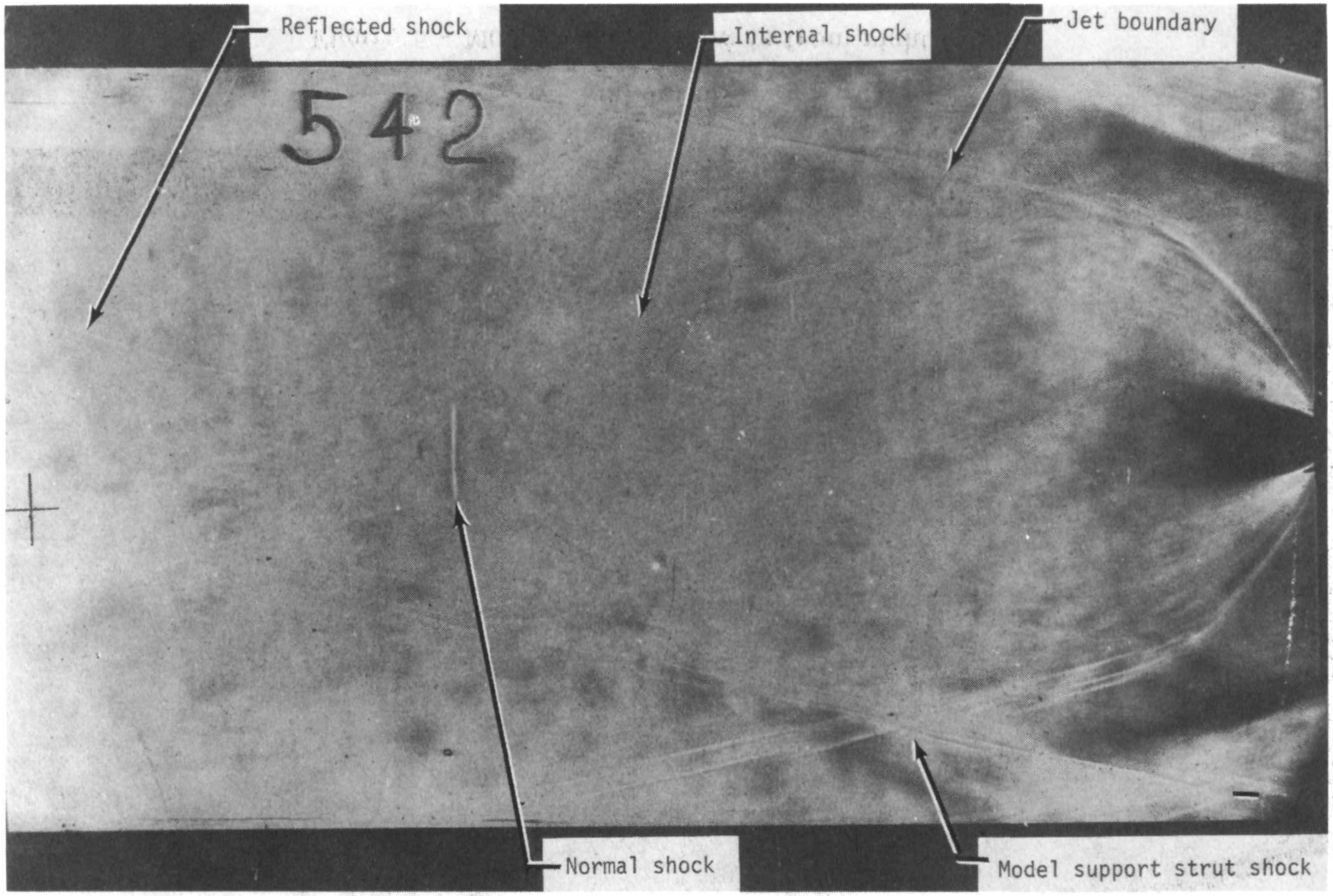
(a) Jet off.

Figure 5.- Model wake. (Flow is from right to left.)



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(b) Jet on.

Figure 5.- Concluded.

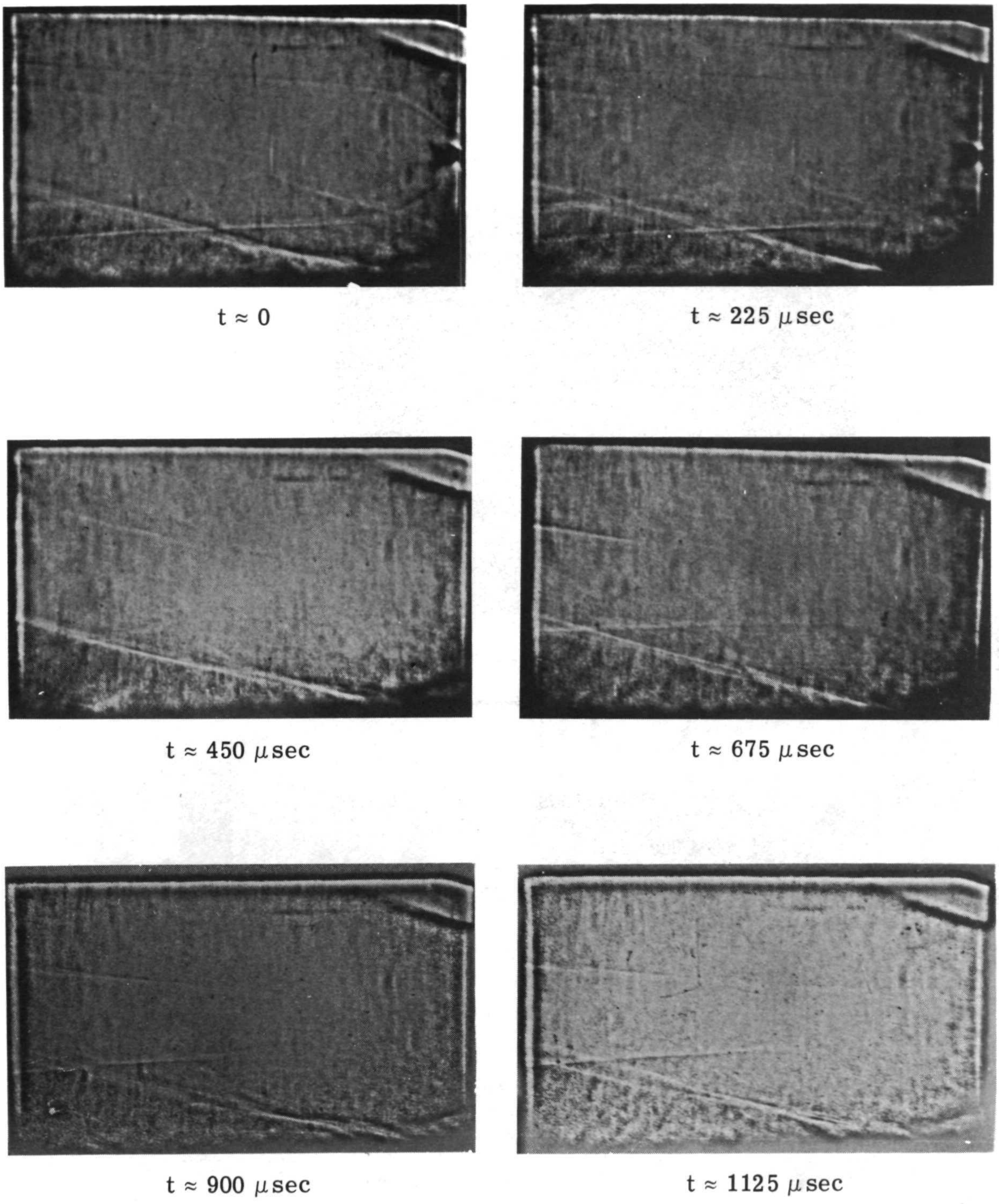
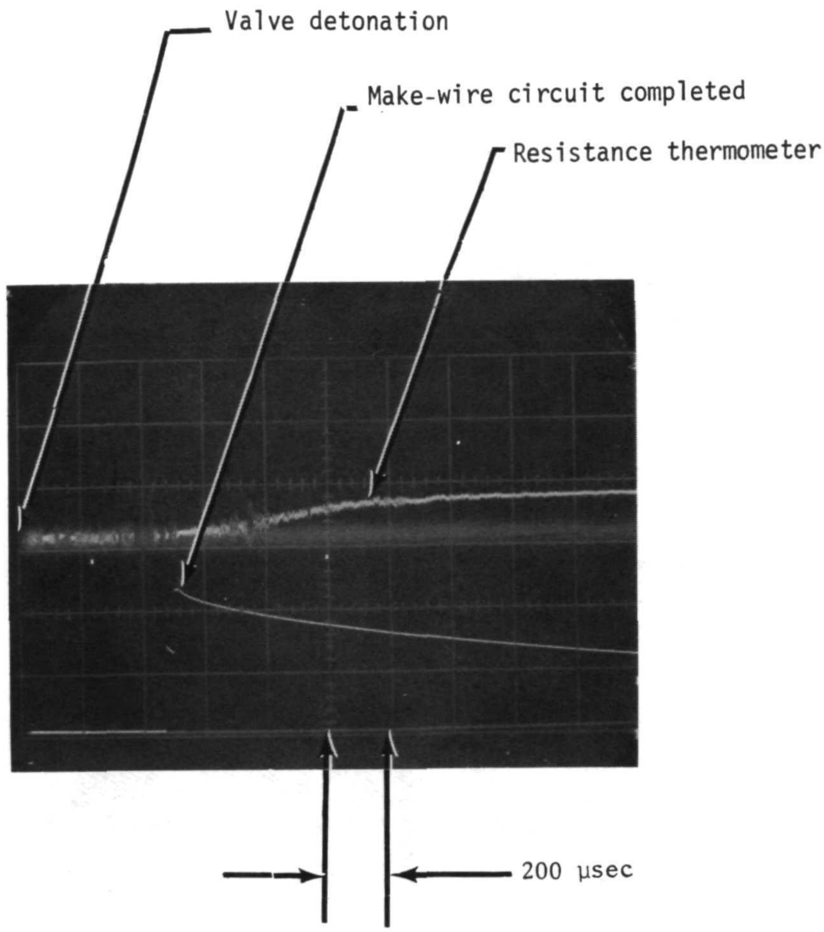


Figure 6.- Schlieren photographs showing disappearance of base jet and formation of wake-recompression shock. (Flow is from right to left.)



CONDITIONS

Wind Tunnel:

$p_t = 2.86$ MPa

$T_t \doteq 506$ K

Model:

$p_t = 3.55$ MPa

T_t = Room temperature

$$p_b = \begin{cases} 560.0 \text{ Pa} & \text{(air off)} \\ 666.6 \text{ Pa} & \text{(air on)} \end{cases}$$

L-74-1047

Figure 7.- Oscilloscope record of time for resistance thermometer to reach equilibrium.

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